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ABSTRACT

This paper describes a means for flying existing Sounding Rocket payloads aboard the Space Shuttle by developing small experiment carriers which become detached from the orbiter and are later retrieved and reused. An effort is underway at the Goddard Space Flight Center to develop such a carrier which would be flown as an Experiment of Opportunity Payload (EOP). The activity is viewed as a feasibility test, and success will encourage the construction of similar packages for additional sounding rocket experiments, for eventual evolution of pointed sounding rocket experiments into the Space Shuttle.

INTRODUCTION

With the introduction of the space shuttle, many scientists look forward to the opportunities to fly their experiments on orbiter missions. The types of proposed experiments vary in size, power, and pointing requirements as well as in discipline. While certain experiments will be engineered to operate in the context of a system such as Spacelab or the Space Telescope, other investigators will want to explore ideas which require short preparation and planning, allowing low cost and flexibility in the science objectives.

One approach for meeting this need is with the Small Self-Contained Payloads or Get-Away Special (GAS) as it is more commonly known, under development by NASA, which offers a means for inexpensive research in space. The GAS program maintains low costs by having as few operational requirements and interfaces as possible with the orbiter systems. Each user constructs his experiment (including the necessary power and data systems) to fit in a small container provided to him by NASA. The only assistance from the orbiter is through the GAS Autonomous Payload Command System (APCS) which allows a set of relays in each experiment to be latched or unlatched by a crew member at the aft flight deck. The GAS program is set up to encourage space research, but many investigations cannot fit within its ground rules because of limitations on power, weight, and a need to be pointed and stabilized on specific targets in the sky.

Several methods of placing low cost pointed experiments on the orbiter have been investigated. One approach meant to reduce orbiter interfaces is to place the experiment outside of and away from the orbiter bay where observations do not interfere with other shuttle operations. With orbiter sortie missions lasting perhaps a week, small payloads could be left detached for several hours or even days and retrieved prior to return to Earth.

The design of such a detached payload is discussed here. Recently, the Goddard Space Flight Center has begun construction of a freeflying payload as an Experiment of Opportunity (EOP) for demonstrating the practicality of low cost pointed operations. The payload would be deployed with the Remote Manipulator System (RMS) at a convenient point in the timeline (Figure 1). At a safe distance from the orbiter, a timer would initiate a sequencer which contains stored instructions. Attitude control authority is enabled next, beginning with acquisition. After the gyro reference is established, maneuvering and stabilizing on preselected targets is possible and the total observation time could stretch over many hours and targets. Meanwhile, experiment and housekeeping data would be stored in a tape recorder aboard the carrier. At the conclusion of the observations the sequencer commands the carrier to orient itself at a predetermined attitude and hold in a low power mode to await rendezvous and pickup by the orbiter. After retrieval it is totally powered down and berthed in the bay for the remainder of the flight.

The EOP design is built upon the base which has been developed at the Goddard Space Flight Center to support the NASA Sounding Rocket Program. The experienced personnel, flight proven hardware, and Sounding Rocket operating techniques in payload development, integration, and testing will be used wherever possible.

GENERAL CHARACTERISTICS

Payloads will be designed to be as independent of the STS as possible. The only operational interfaces envisioned are the latching release and berthing support, the deployment and retrieval using the Remote Manipulator System (RMS), and the requirement for an initial turn-on from the aft flight deck. This independence allows for a fairly rapid response to opportunities for flight, and would even permit the use of "standby" payloads which could conceivably be added to the manifest in a matter of weeks. It is an ultimate goal that manifesting for EOP payloads would be done on a "space available" basis.

Supporting subsystems, which, along with the experiment, would comprise the complete EOP system would come directly from Sounding Rocket inventories. Technology from the GAS Project would be used where possible. For example, the APCS would be used to activate an EOP carrier prior to deployment.

Safety is important. The EOP/Sounding Rocket pneumatics and mechanical subsystems are conservatively designed to be compatible with a launch environment and so far no serious safety problems have been encountered.

Figure 2 illustrates the relationship of existing Sounding Rocket hardware systems and EOP. The EOP package generally would be rectangular weighing around 1000 lb. It could operate for up to 24 hours while detached from the orbiter. Data would be stored on an internal tape recorder to eliminate the need for an RF link. No special orbit requirements exist at present, since pointing programs and target selection can be adjusted prior to flight to compensate for any chosen orbit. The ACS thruster system will use cold-gas (GN_2) as a propellant and will have the thruster nozzles positioned to provide only rotation about each control axes.

EOP TEST MISSION

The EOP concept has been endorsed by NASA, and work has begun on a first EOP mission. This initial effort, if successful, will pave the way for future EOP missions based upon Sounding Rocket experiments. The subsystems described below are earmarked for the EOP Test mission and the general concepts advocated by EOP are best illustrated by the specific example of EOP Test.

The EOP Test Payload has a rectangular shape with the selected experiment occupying about half the volume and the support subsystems occupying the rest. The support subsystems which are adaptations of rocket systems can be grouped into four major areas:

- Attitude control electronics and sensors (ACS)
- Cold-gas thruster system for attitude maneuvering
- Instrumentation and data management
- Power system

Experiment

The experiment to be flown aboard EOP Test is one which has been flown numerous times aboard NASA Sounding Rockets (Figure 3) in conjunction with the U.S. Naval Research Laboratory in Washington, DC. It will scan various cosmic X-Ray sources at rates of 10-20 arcseconds per second to provide high resolution X-Ray data over an energy range of 0.5-15 Kev. The observations will be used for studies of emission processes in clusters of galaxies and the exploration of the galactic center. The NRL experiment is .507m x 1.07m x 1.07m (20" x 42" x 42"), and thus fits well into the rectangular packaging concepts chosen for the first EOP. Mechanical and electronic refinements are currently under way to adapt this experiment for the EOP mission.

Data Storage and Handling

As stated previously, RF links from the EOP package to the orbiter will not be used, so all experiment and housekeeping data must be stored aboard the EOP carrier. The MARS 1400 airborne tape recorder (Figure 4) has been chosen for the EOP Test mission. This machine, while comparatively heavy and inefficient in terms of power usage, offers advantages which make its use on EOP advisable:

Multiple Tracks (14)

Switchable Tape Speeds

10^{10} Bit Storage Capacity

Rugged and Proven (High Performance Aircraft)

Since this device is currently in the GSFC Sounding Rocket inventory, its use aboard EOP is feasible and indeed desirable.

The Sounding Rocket micro PCM data handling system (Figure 5) will be used to format and handle both experiment and housekeeping data. The advantage of this data handling system for EOP is its reliability (proven on over 100 rocket flights), compatibility with Sounding Rocket experiments now in existence, and operational flexibility, i.e. it accepts a wide variety of input signals without preprocessing. A minor change is required because EOP Test will use a lower data rate than that used on rockets.

Attitude Control

The attitude of the EOP package will be under the control of a modified Stellar Tracking Rocket Attitude Positioning System (STRAP) System, the basic elements of which are shown in Figure 6. The STRAP System has proven itself in over 150 successful rocket flights.[2,3]. The STRAP system for EOP will use Tuned Restraint Inertial Gyros (TRIG) as the basic inertial reference (Figure 7). These gyros, when used in conjunction with stellar and solar sensors/trackers taken from Sounding Rockets will permit the following basic pointing:

Accuracy $\pm$ 3 arc minutes

Limit cycle $\pm$ 5 arc seconds

Drift rate < 0.1 deg/hr.

Periodic stellar updates and an aspect camera will compensate for the small amount of gyro drift. Target sequencing and additional system logic will be under the control of a microprocessor directed programmer which is currently being designed . A ruggedized version of the Z80 S+50 Standard Bus will be used. Pointing Programs will be stored on PROMS and hence ACS operating time and targets are limited only by consumables (power and control gas).

Pneumatic Thruster System

The pneumatics system will be comprised of solenoid valves, requlators, and other components which have proven their reliability aboard many Sounding Rockets, and are currently in the inventory. Two 3000 cubic inch gas vessels are currently being procured. Figure 7 is a schematic of the pneumatics subsystem. A dual nozzle exhaust for each control valve is desired over other possible pneumatic schemes to keep the implementation simple, yet safe. In the event of a valve failure, no significant translation would occur.

Power

The power subsystem will again call on the technology of Sounding Rockets by using Silver Zinc storage cells to provide power. The cells are several times larger than the standard Silver Zinc HR3/HR5 flown aboard Sounding Rockets, but their handling and performance is similar. The cells will be packaged in sealed containers with overpressure vents, even through special materials and processes will preclude significant amounts of gas generation. Electronic circuitry developed for the GAS program will be used to monitor the temperature and voltage of each cell, and loads will be removed via the GAS Payload Power Contactor (PPC) in the event of anamolous behavior. EOP Test is currently configured to utilize two 19 cell packs of LR 130 cells for 8 KwH, and one 19 cell pack of LR 290 cells for 9 KwH. A total maximum capacity of 17 KwH would easily allow 24 hr. operation, with ample reserve for in-bay heating, if necessary. In the event mission time is shortened, or thermal requirements for in-bay heating do not materialize, one or more packs can be deleted.

Item	Power (WATTS)	Energy (KWH)
X-Ray Telescope	25	0.6
Attitude Control System	110	2.7
Tape Recorder	95	2.2
PCM Data System	25	0.6
	255	6.1
Payload Warming	30	3.6
Contingency (20%)		2.0
		11.7

Thermal Control

The thermal system, and indeed even the requirement for such a system, represents an area of technology new to most rocketeers; however, heat rejection is a concern even in short-duration missions like EOP and as such it must be dealt with. The NRL experiment, along with other Sounding Rocket subsystems will operate properly within a rather broad range of 0-50 deg C. Heaters will be used in the experiment collimators to keep their thermal gradient below a specified value. All large heat-producing components (mainly the ACS and Tape Recorder) will be mounted on aluminum plates which serve as cold sinks. To maintain sink temperatures so that internal temperatures stay within 25 deg C $\pm$25 deg C, a simple control system slides motor-driven doors to expose the outside facing sides of these plates to space. Paint and tape will also be used when indicated by thermal analysis and tests.

Payload Configuration

Each subsystem is mounted separately to allow independent servicing. The batteries are placed in the center of the payload because of their heavy weight. Each of the other subsystems is mounted on outside-facing plates which also serve as thermal dissipators. These plates comprise the rear and sides of the carrier. The experiment aperture is on the front of the payload and is protected by doors which are open when an observation is being made or the startracker is being used to update the gyro reference. Alignment is critical between the X-ray telescope collimators, the startracker, and the experiment aspect cameras; consequently, all are secured to a common optical bench mounted in the experiment section of the payload.

The attitude control electronics and sensors (except for the startracker) are arranged and attached to the inside surface of a plate mounted on one of the payload sides, similarly, the instrumentation and data system which includes the tape recorder is mounted on the other side. As mentioned before the plates are intended to serve as a heat sink since both systems will dissipate considerable power ($\sim$100 watts per plate).

The two control gas tanks are secured to the plate at the rear of the carrier. The thruster control valves are placed in a manifold which will be mounted to this plate.

From each valve come two exhaust lines which go to a pair of opposing nozzles mounted elsewhere on the package. Since the ACS and Instrumentation systems are attached to plates, they will be serviced by removing the entire plate. The batteries can be inserted through the top prior to installation of the grapple fixture and the gas tanks filled through a fill port on the side.

On the exterior (Figure 9), secured to the top, is the RMS grapple probe and docking target. On the bottom is the orbiter attachment fixture. Also on the outside are the ACS thruster nozzles and several small sun sensors used in the acquisition.

The structure is still being designed, although it is likely that the carrier will incorporate an aluminum framework structure assembled from commercially available extrusions. Honeycomb plates covered with thermal blankets and beta cloth will be used to form the sides, in a sense, wrapping the interior in a cocoon that is regulated in temperature by thermally-controlled doors on the side and the heat loss through the experiment aperture.

ORBITER INTERFACES

Attachment to the Orbiter

The mounting system must be able to provide straightforward release and reberthing as well as structural soundness during launch and landing. The expense of qualification of such a system for the shuttle implies that the best approach is to find a mounting system that has been tested and qualified. The most attractive approach that has been found is the REM system which has been developed by Marshall Space Flight Center for the IECM experiment to be flown on the Orbiter Flight Tests. The REM (Figure 10) can be supported on a bridge structure similar to that used for the GAS Payloads. The possibility of using a sidemounted scheme is also being investigated.

Payload Function Control

The method to be used by EOP to activate the payload prior to deployment will be via commands sent by a crew member from the aft flight deck using the APCS which has been developed for the GAS Program.[4] This system makes use of a small hand-held keyboard stowed inside the crew cabin which connects to special wiring installed in the payload bay. The APCS provides the capability for commanding relays in the payload to latch or unlatch and verifying to the astronaut that the switching has occured.

A microprocessor based sequencer now under development for Sounding Rockets will provide overall payload event sequencing after RMS pickup and release. The sequencer will provide flexible programming, low power consumption, and multiple discrete outputs.

TESTING

The EOP Test package will undergo a "standard" Sounding Rocket integration at GSFC. The package will be assembled and electrically checked in the manner of Sounding Rockets. All mechanisms will be tested and the optical attitude sensors (stellar and solar) will be aligned to the experiment. Once the package is assembled, aligned, and fully operational, a protoflight vibration test will be performed, mass properties will be measured and other required environmental tests will be performed. At the completion of the environmental testing, the package will undergo operational rechecks and sensor realignments. When these final tests are successfully performed, the EOP Test Package will be shipped to the KSC in a ready-to-launch condition.

When the package is unpacked at KSC it will be checked for shipping damage and its overall health will be determined to the extent possible without disassembly. Flight batteries will be inserted and the gas tanks will be filled. Finally, the package will be integrated with its mount/release fixture and placed in the Orbiter.

OPERATIONAL SEQUENCE

Since EOP will not operate during launch, the first event of interest will occur when the crew member uses the APCS to energize the EOP Test payload in preparation for its release. On this command all subsystems monitors will be energized, initiating a self check routine that occurs automatically inside the payload. When all subsystems indicate readiness, the running lights aboard the EOP carrier will be turned on, giving a visible indicator of readiness to the crew member.

Details on the RMS pickup and release are not yet defined, but the process is envisioned as being straightforward. There are no special attitude requirements during release.

When the RMS releases the EOP Test Package, a switch aboard EOP will detect it. This serves as a start command to power up the necessary subsystems. After a TBD time interval to allow the orbiter to back away from the EOP Test Package, the ACS is activated and acquisition begins.

The ACS will first null all body rates-of-turn by firing the appropriate thrusters. Next, a wide angle solar acquisition scheme utilizing Sounding Rocket solar sensors will be used to align two payload axes perpendicular to the sun. At a specific point in the orbit a slow rotation about the solar line-of-sight is made (Figure 11), until a startracker (mounted orthogonally to the sun sensor) with special discrimination logic, acquires a designated star approximately at right angles with the sun. This solar-stellar acquisition scheme will provide an initial three axis "fix" for the payload to an accuracy on the order of 1 arc minute.

The preprogrammed functions stored in the ACS programmer are activated next, beginning with a controlled slew to the first target at about 1^{o}/sec. After stabilization on target the experiment data collection begins. While on the target a series of slow finely controlled scans may be made. This process, i.e. maneuvering, stabilization and/or scanning is performed in concert with periodic stellar updates to keep the gyro reference within 1 arcmin. The sequencing can be designed to insure that there is no interference from earth albedo or other sources of blanking.

When the pointing program is completed, the package will be oriented by the ACS so that the grapple will have a known orientation for orbiter pickup. This involves rotating the package about an axis perpendicular to the orbital plane at the orbital rate. The Orbiter will return to the package, reattach the RMS, restow the EOP package, and continue its mission.

Orbiter activities during EOP operation, and details of stationkeeping, radar aids, visual cues, maximum mission time, etc. are not yet resolved. Studies performed at GSFC have shown that the normal separation between the orbiter and rectangular EOP over a 24 hour period, will be on the order of a few km., and orbiter attitude will determine whether EOP or Orbiter leads the separation process along the velocity vector.

RISKS AND UNCERTAINTIES

While the expenditure of resources (both manpower and dollars) to obtain the first EOP is relatively small when considered in the light of other space programs, the risks and uncertainties are real and significant.

The crucial question is whether the STS will be accessible to those who employ a less formal approach to design, assembly, and test than has been used in other manned programs. Safety remains of paramount importance. The GAS program has preceded EOP in pioneering the informal approach using sounding rocket design techniques. The results to date are encouraging, but only time will tell.

In terms of hardware, the sounding rocket personnel are, of course, comfortable with those systems which have direct precedents on sounding rocket systems, namely, attitude control, instrumentation and data handling, mechanisms and structures, as well as the experiment itself. The chances of failure are, therefore, small with these systems. The thermal and power system areas represent significant departures from sounding rockets and thus have a higher risk associated with them.

The greatest number of uncertainties to EOP arise in the area of deployment, rendezvous and retrieval. The exact implementation in this crucial technical area depends upon factors not within the control of EOP designers. Indeed, they will affect EOP design. Such questions as mission length, rendezvous procedures, Reaction Control System fuel availability, radar tracking requirements, and safety constraints to prevent recontact must be answered by those organizations responsible for them before an EOP can be flown.

COST

The goal of the GSFC sounding rocket organization is to produce an EOP carrier for cost which compares with the cost of a complex pointed rocket payload. It is estimated that these comparable costs will occur after approximately six flights of EOP carriers. Indications to date are favorable in the cost area. Of course, the cost estimates do not include any costs associated with services provided by the STS.

STATUS

The NASA Office of Space Science has approved request of the sounding rocket organization at the GSFC to proceed with the design and construction of an EOP test package. This effort is now taking place within the confines of the NASA sounding rocket program, and work has begun in earnest at the GSFC. Long lead items are being procured, mechanical devices and structures are being designed and fabricated, and subsystem logic designs are proceeding. The goal of EOP test is to begin a planned 2-month carrier integration by July 1, 1981, at the GSFC.

The Payload Integration Plan is not yet complete and many items remain to be resolved; however, there have been no unsolvable problems presented to date.

CONCLUSION

The EOP concept represents a natural evolution of sounding rockets into the shuttle era. It presents an avenue for using the shuttle to conduct the low-cost, quick-reaction scientific observations that have distinguished sounding rockets in the past. The observations can be conducted for approximately the same cost as for sounding rockets, but the larger viewing time will increase the data return by orders of magnitude.

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2. Greeb, M.E. and Shrewsberry, D.J., "Stellar Tracking Rocket Attitude Positioning (STRAP) System," AIAA 2nd Sounding Rocket Vehicle Conference, Dec 7-9, 1970.

3. Shrewsberry, D.J., et al. "STRAP IV -- High Accuracy, Low Drift Attitude Control System," AIAA 3rd Sounding Rocket Technology Conference, March 7-9, 1973.

4. Hudgins, J.I,. "An Autonomous Payload Controller for the Space Shuttle," AIAA 5th Sounding Rocket Technology Conference, March 7-9, 1979.

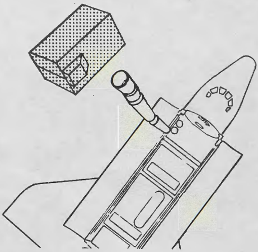

Figure 1 - A payload flown as an Experiment of Opportunity would be deployed to operate free of the orbiter.

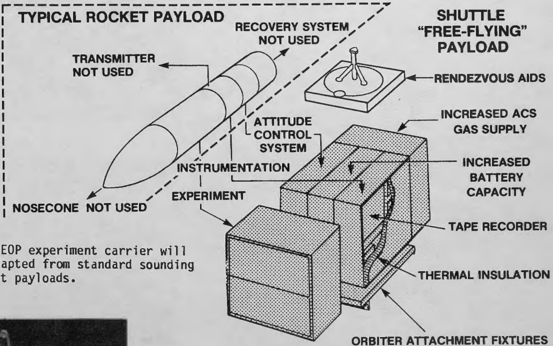

Figure 2 - The EOP experiment carrier will be adapted from standard sounding rocket payloads.

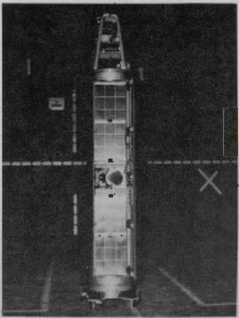

Figure 3 - This X-Ray telescope, developed by the Naval Research Laboratory has two large area apertures which view out the side of the payload once the doors are opened in space. Between the two halves of the telescope are the startracker and aspect camera.

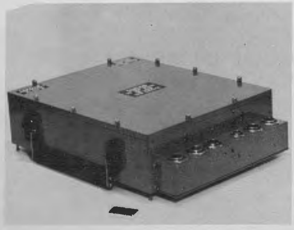

Figure 4 - The MARS 1400 Tape Recorder (60 cm x 40 cm x 16 cm) is the data storage device for the EOP Test Payload.

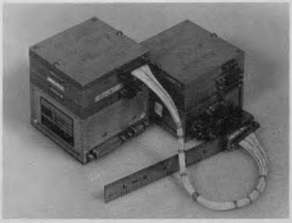

Figure 5 - The PCM system developed at GSFC is shown here. Used on sounding rocket payloads the unit is small and lightweight, yet flexible in its interfaces and able to handle data rates as high as 200K.

Figure 6 - Shown here are elements of the STRAP system. (clockwise from upper left) electronics module, startracker, inverter/power supply, sequencer.

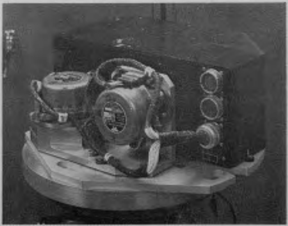

Figure 7 - The inertial reference attitude platfrom consists of two TRIG gyros mounted with its associated electronics module. The electronics module, in turn, connnects to the electronics module shown in Figure 6.

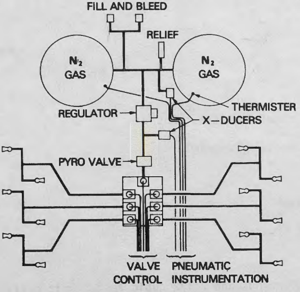

Figure 8 - Schematic of the cold gas pneumatic thruster system. Valve control and pneumatic instrumentation lines connect to the STRAP system.

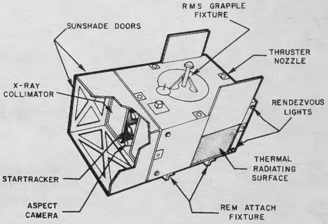

Figure 9 - The EOP Test Payload is shown here.

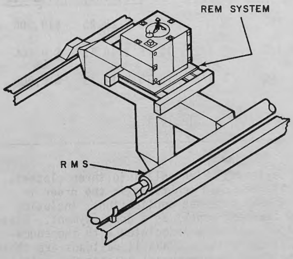

Figure 10 - One concept for mounting the EOP Test Payload is shown here.

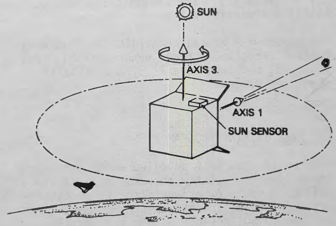

Figure 11 - Acquisition would use a sun sensor to point axis 3 to the sun. Then, rotation about the sun line of sight sweeps the startracker (axis 1) until it acquires a programmed reference star (e.g. Canopus).